Edition 4.0 Energy Balanced and Filled (EBAF) – TOA

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Fall 2017 CERES Science Team Meeting, Sept 26-28, 2017, NASA GSFC

CERES EBAF TOA Product

- Uses an objective constrainment algorithm to adjust SW and LW TOA fluxes within their range of uncertainty to remove any inconsistency between average CERES global net TOA flux and the Earth's Energy Imbalance (EEI) inferred from:
  - Upper ocean heat storage measurements
  - Estimates of ocean heat storage below 2000 m
  - ice warming and melt
  - atmospheric and lithospheric heating
- Uses combined CERES and MODIS data to produce gap-free clear-sky regional TOA flux maps.

EBAF-TOA Ed2.8 (Previous Version)

- Essentially a hybrid of:
  - Clouds & ADMs used in CERES SSF Ed2 (same as Ed3)
    => GEOS 4 (03/2000-12/2007), GEOS 5.2.1 (01/2008-)
    => MODIS Collection 4 (03/2000-04/2006) & 5 (05/2006-)
  - TOA fluxes determined using Ed3 calibration coefficients

- While input changes have minimal impact on all-sky TOA fluxes, they cause discontinuities in clear-sky TOA fluxes and all-sky and clear-sky surface radiative fluxes.

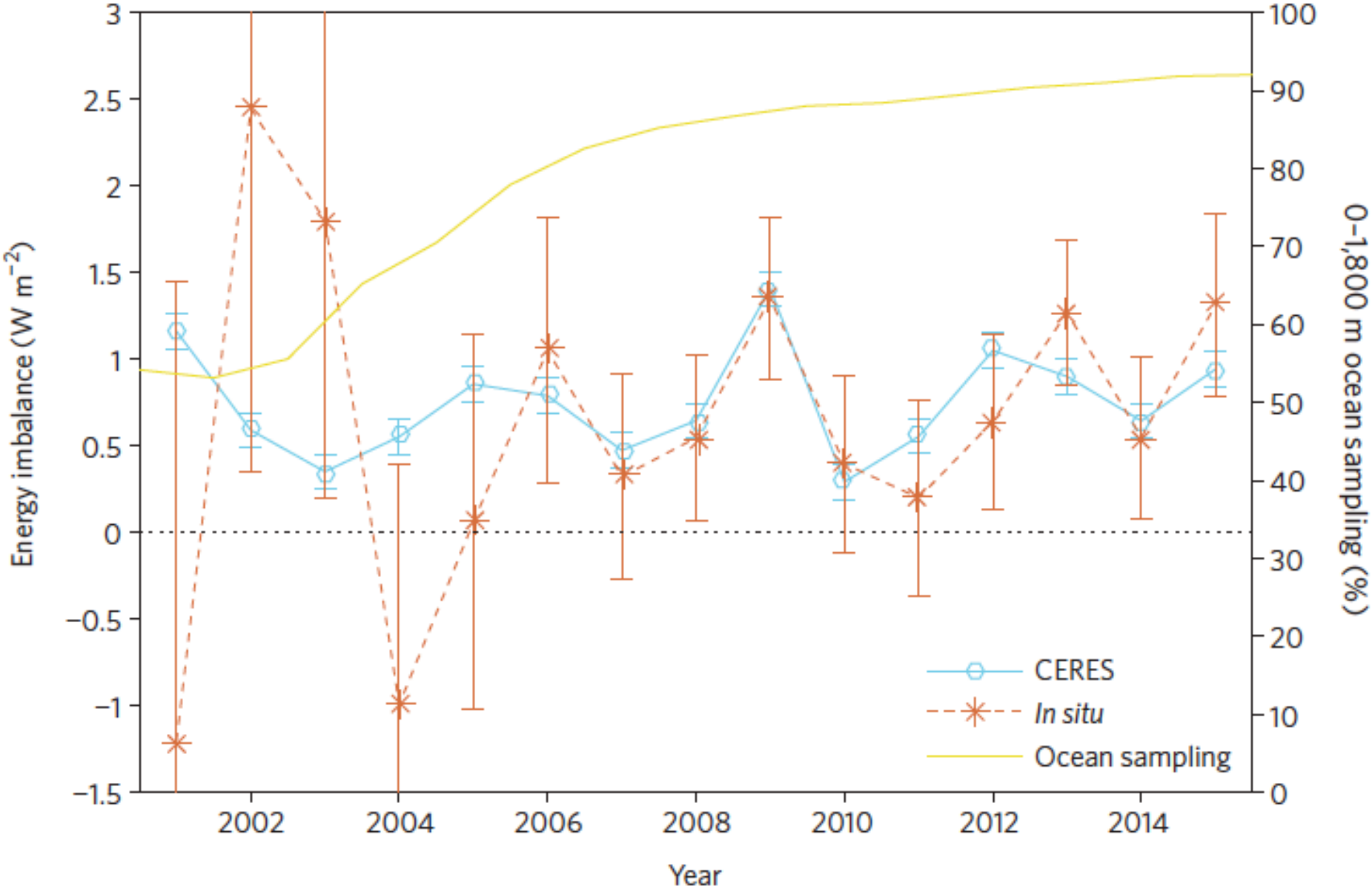
- Consequently, there's a spurious trend in TOA Cloud Radiative Effect.

- EBAF-SFC makes adjustments to minimize impact of input changes.

EBAF-TOA Ed 4.0 (All-Sky)

- Incorporates all of the Ed4 algorithm improvements:
  - Instrument calibration
  - Cloud properties
  - Angular Distribution Models (for radiance-to-flux conversion)
  - Time Interpolation and Space Averaging (with hourly GEOs)
- Based upon consistent met assimilation (GEOS 5.4.1), MODIS radiances and aerosols (Collection5, until that gets superseded by C6 in April 2017).
- GMT instead of local time
- TOA fluxes constrained using 10 years of Argo instead of 5 years.
- Provides some basic MODIS cloud properties (f, τ, p_{eff}) alongside TOA fluxes on CERES ordering tool.

Variability in Earth's Energy Imbalance: CERES vs in situ



EEI Average (2005-2015) = 0.71 $\pm$ 0.1 Wm^{-2}

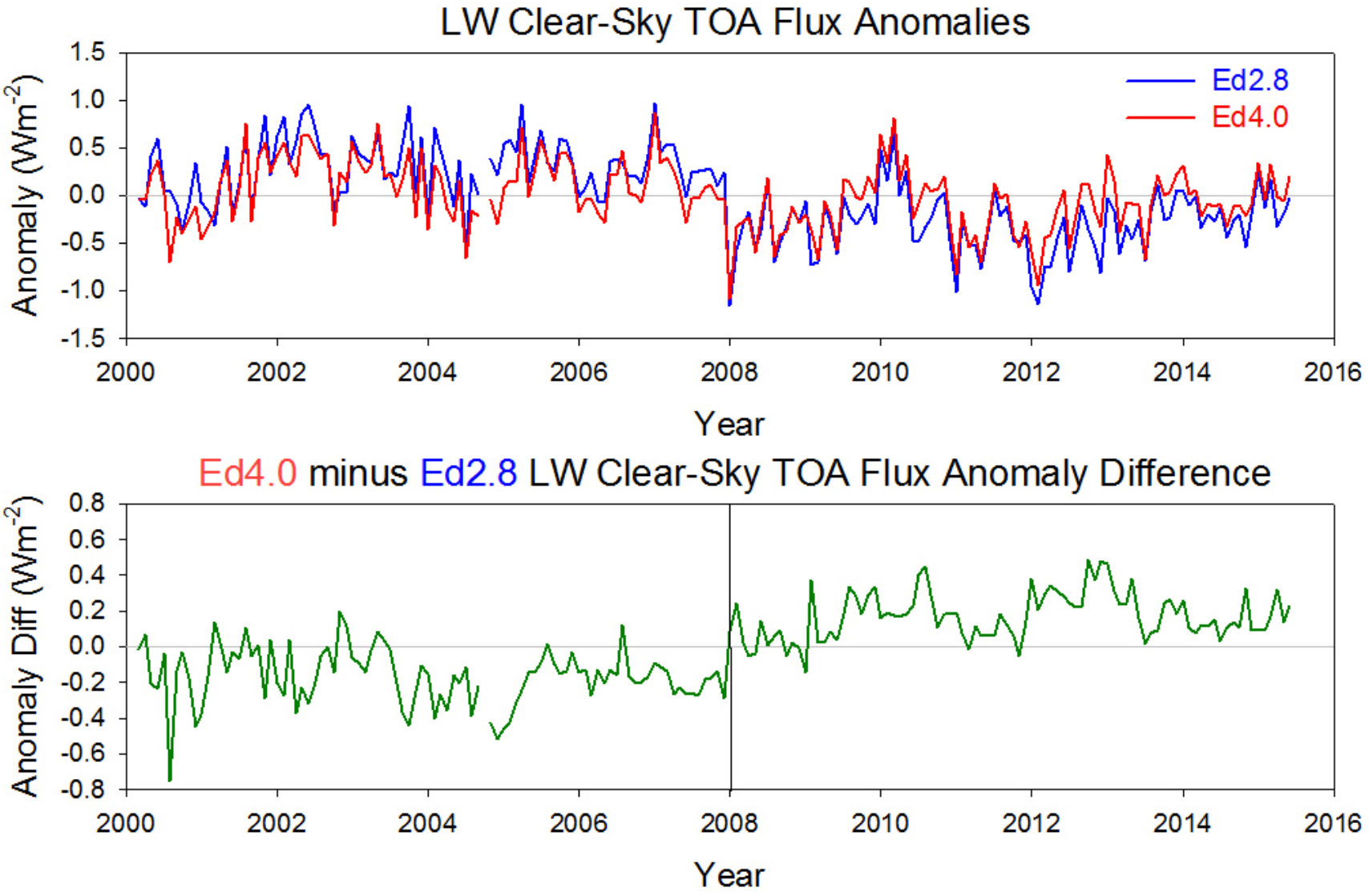
(Johnson et al. 2016)

EBAF-TOA Ed 4.0 (High-Resolution Clear-Sky Fluxes)

- Includes clear-sky fluxes from cloud-free CERES footprints & estimates from clear portions of partly cloudy CERES footprints.

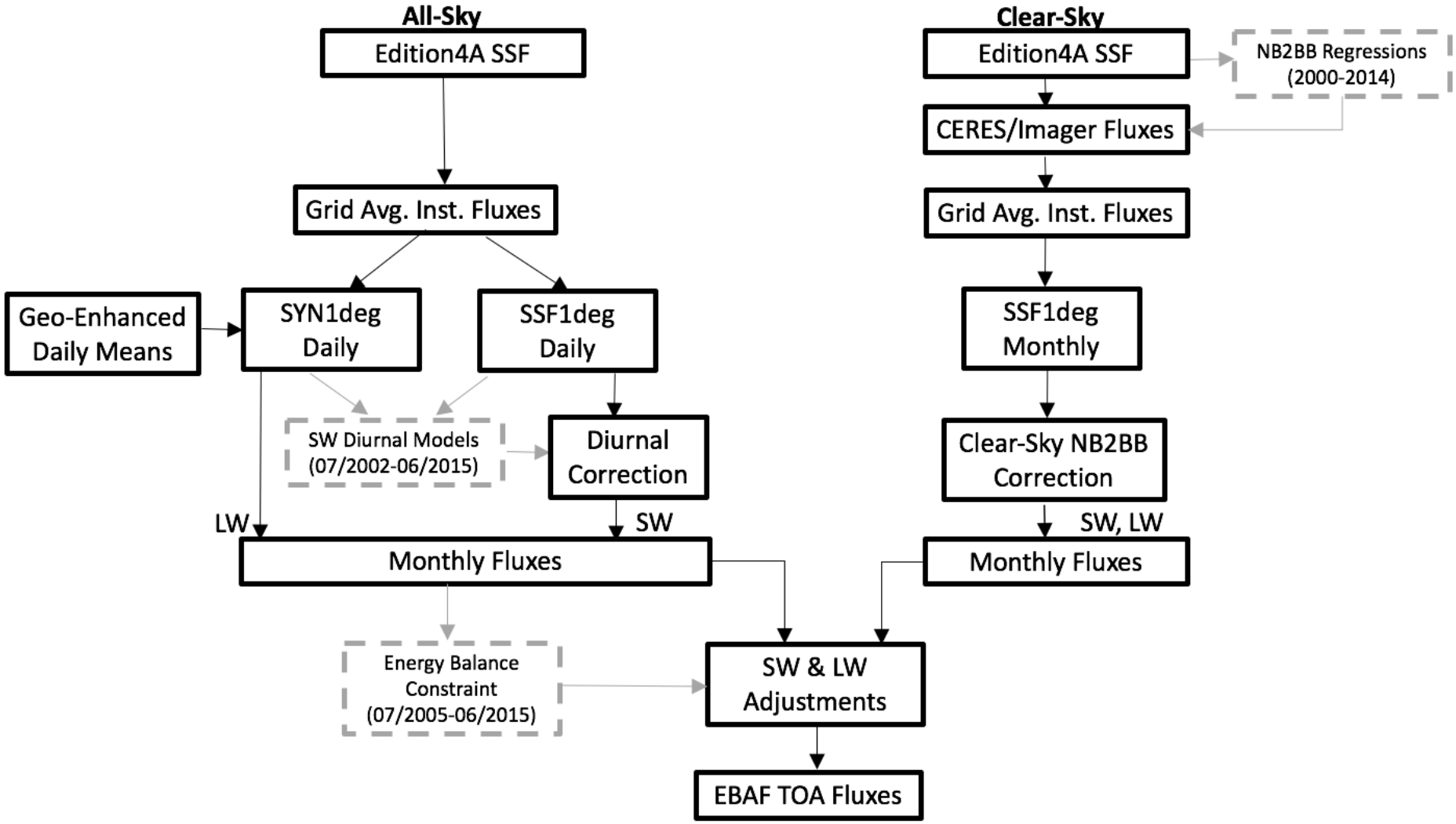
Ed4 Improvements:

- Ed4 MODIS cloud mask & CERES ADMs (Ed4 SSF).
- Improved narrow-to-broadband regressions.
- Infer clear-sky fluxes for CERES footprints with up to 95% cloud fraction.
- Estimate clear-sky fluxes for footprints with partial snow and sea-ice coverage.
- Fix bug found in Ed2.8 SW clear-sky time-space averaging.
  - Ed2.8 erroneously used all-sky directional models (DMs) instead of clear-sky DMs.



- Change in version of meteorological assimilation data used in Ed2.8 in January 2008 causes discontinuity in Ed4.0–Ed2.8 difference.

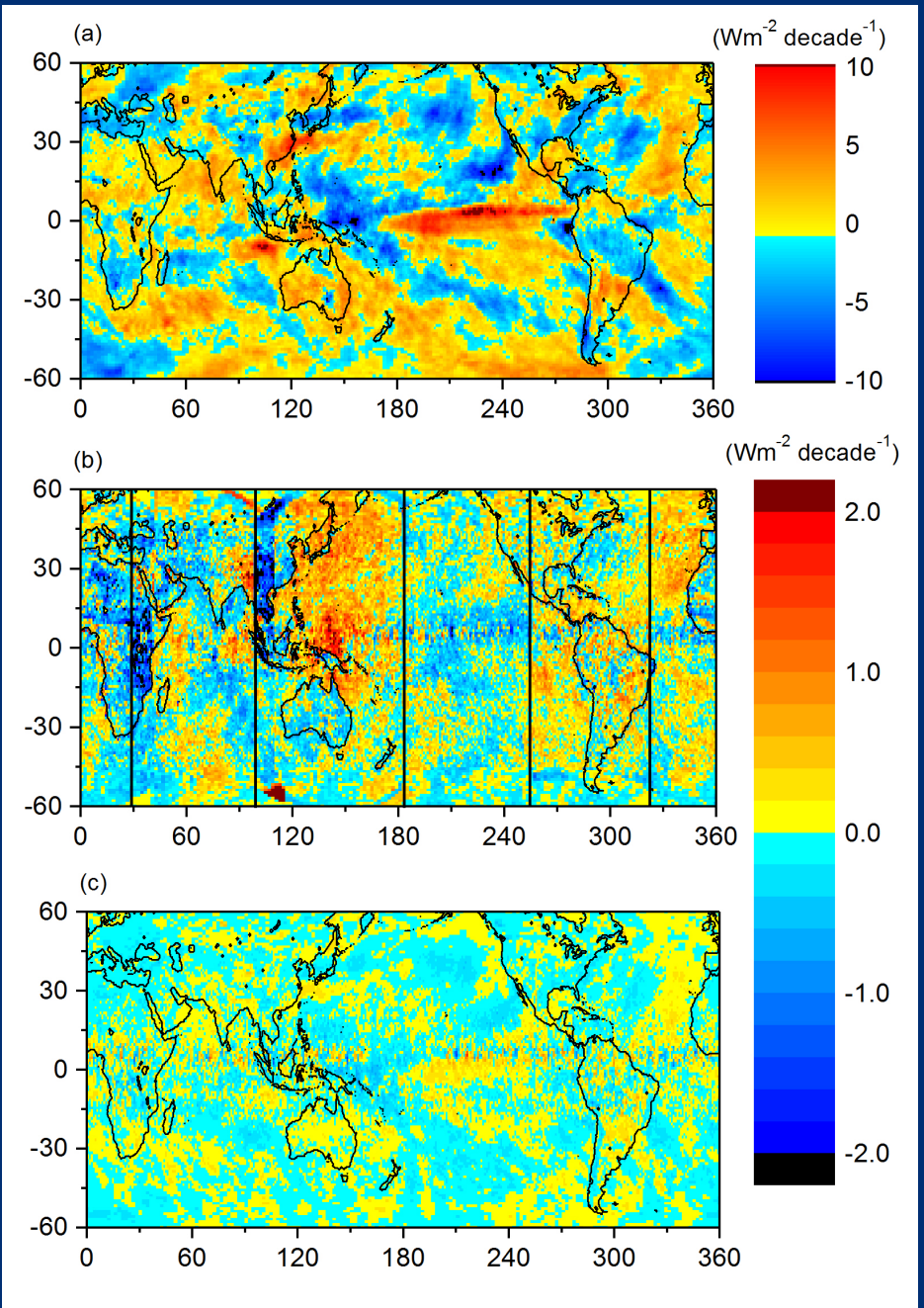
Processing Flow for EBAF-TOA



Gray boxes = pre-processing steps.

Black boxes = routine processing steps.

SW TOA Flux Trends and Trend Differences (July 2002-September 2016)



SSF1deg-Terra_Aqua SW TOA Flux Trend

Trend Difference:
SYN1deg-Terra_Aqua minus SSF1deg-Terra_Aqua

Trend Difference:
EBAF Ed4.0 minus SSF1deg-Terra_Aqua

CERES EBAF Ed4.0 Empirical Diurnal Corrections

- Use daily SYN1deg & SSF1deg files for 07/2002 – 06/2015 to compute climatological monthly mean ratios of SYN1deg-to-SSF1deg sorted by:

  1) Month (1-12)

  2) Surface Type: Open ocean (No snow), Desert, Other.

  3) Diurnal Asymmetry Ratio (DAR):

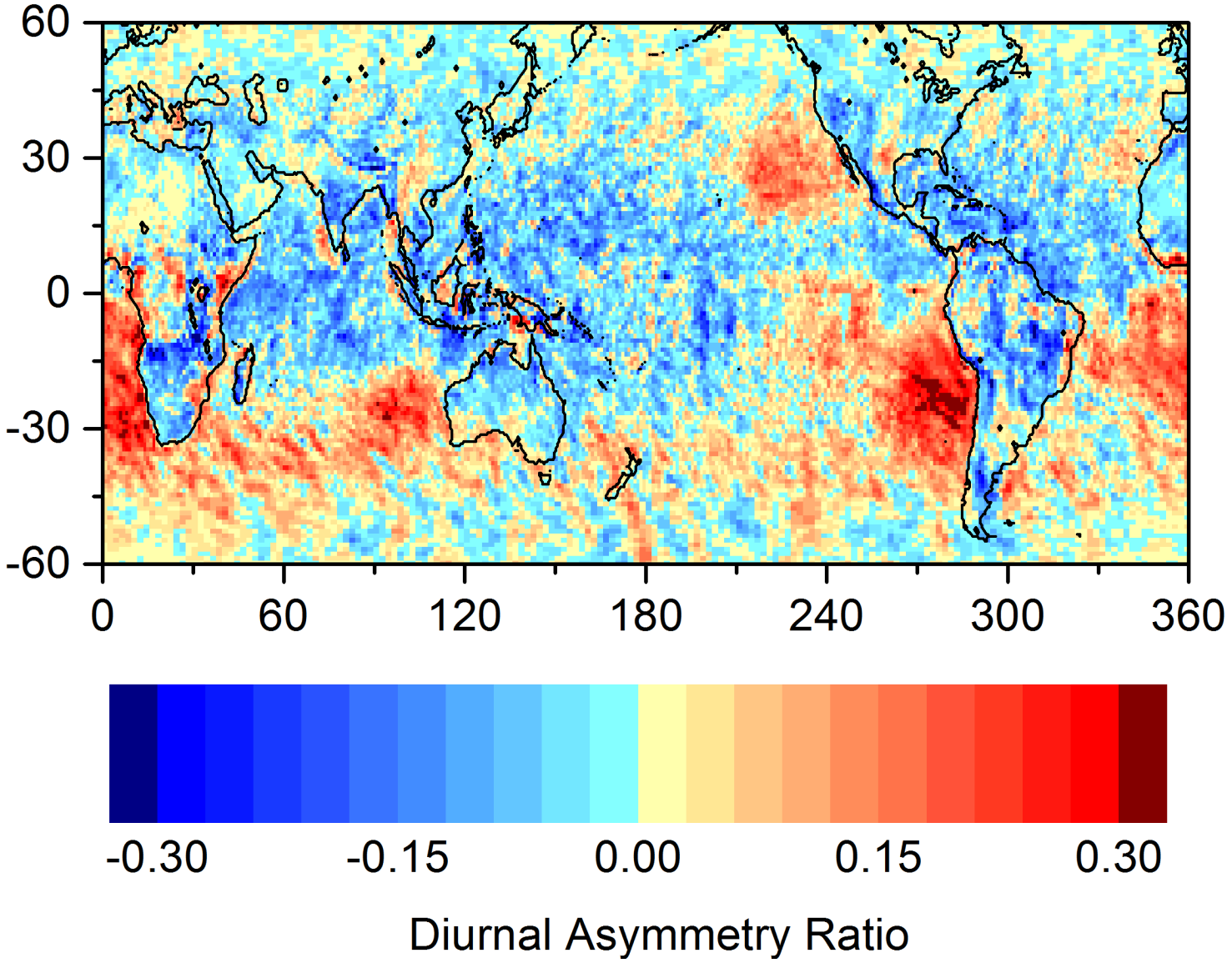
  $$DAR = \{[F^{SW}(morn) - F^{SW}(aft)]/12\} / F^{SW}(24h)$$

- Develop diurnal corrections for Terra SSF1deg, Aqua SSF1deg, and Terra-Aqua SSF1deg.

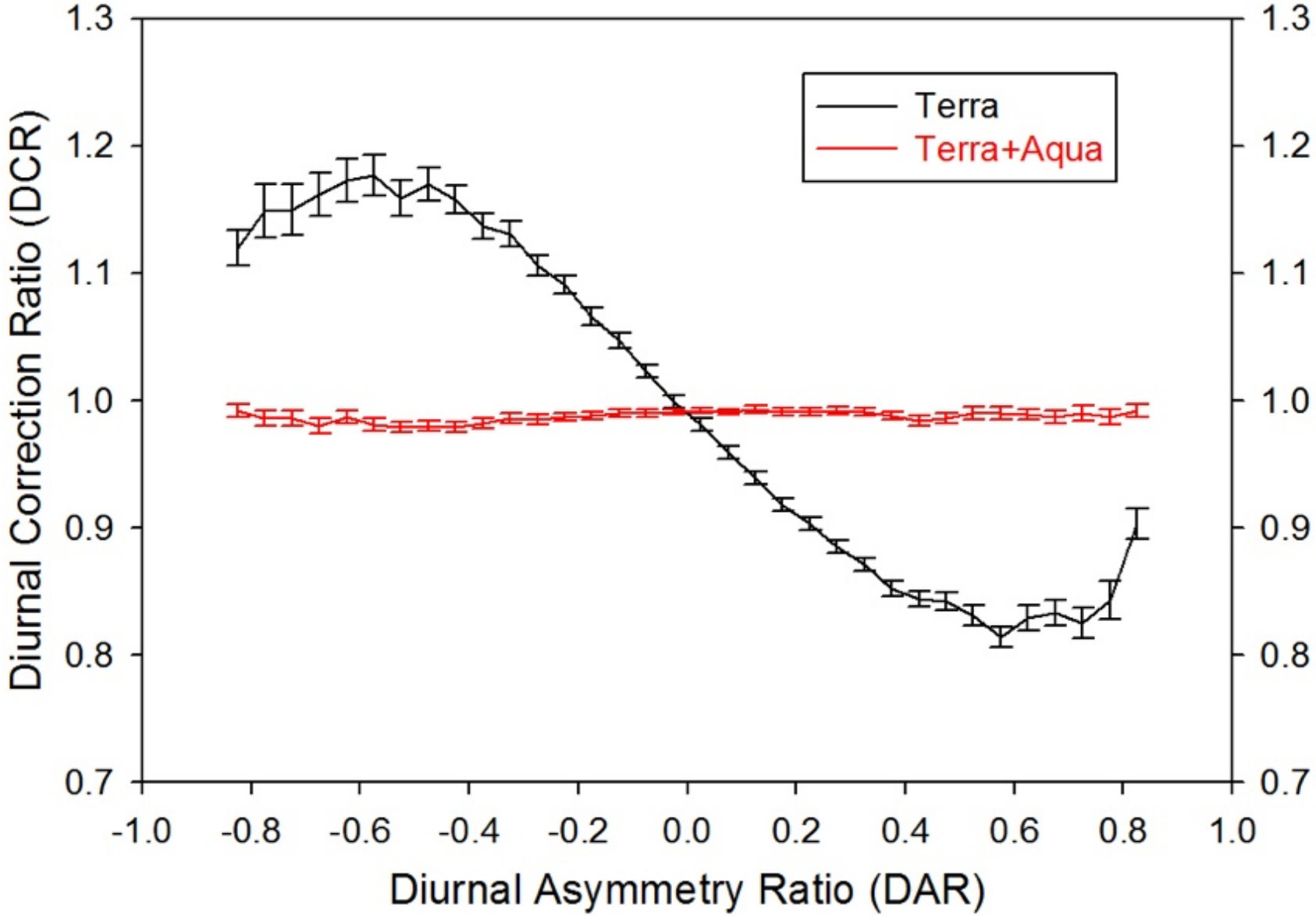
Application:

- Convert daily mean SSF1deg fluxes to diurnally corrected values (“SYN1deg-Like”).
- Average diurnally corrected SSF1deg fluxes to monthly means.

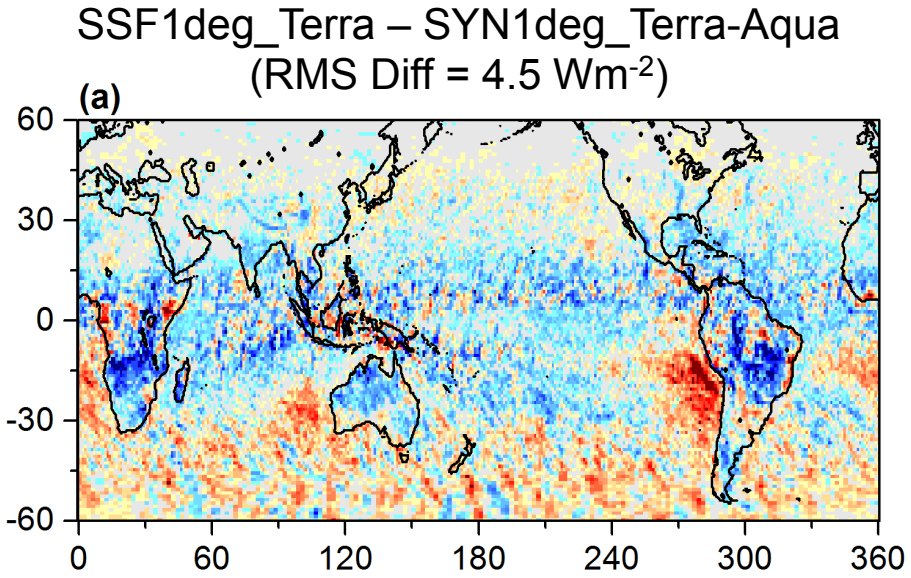
Monthly Regional Mean DAR (October 2008)

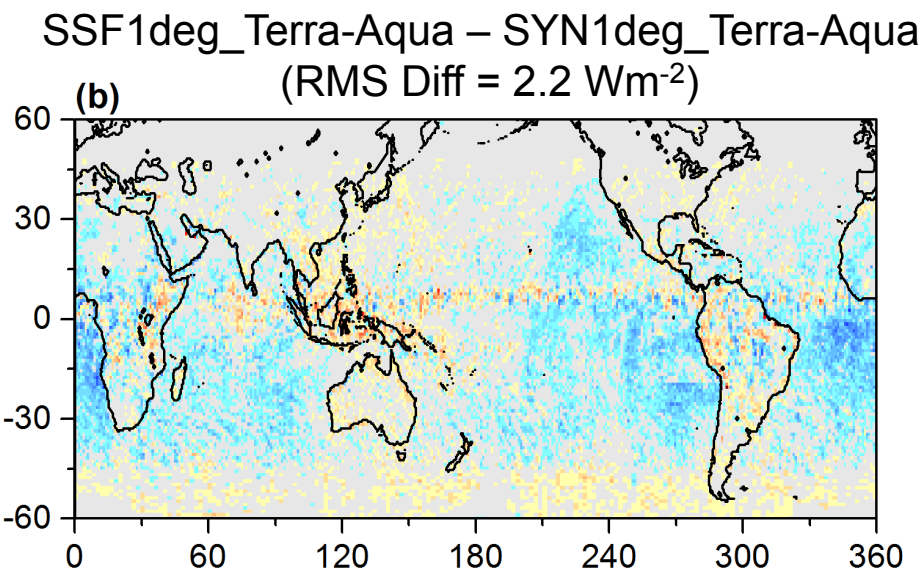


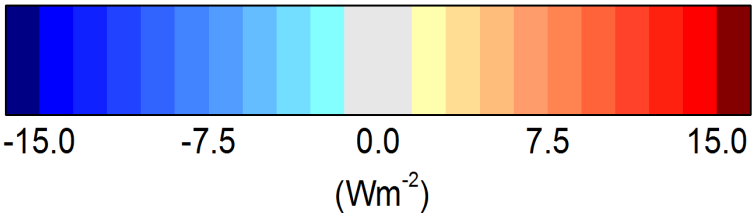
Example of Diurnal Correction Ratios (Latitude Centered on 29.5°S over ocean for July)



All-sky SW TOA Flux Difference: No Diurnal Correction (October 2008)

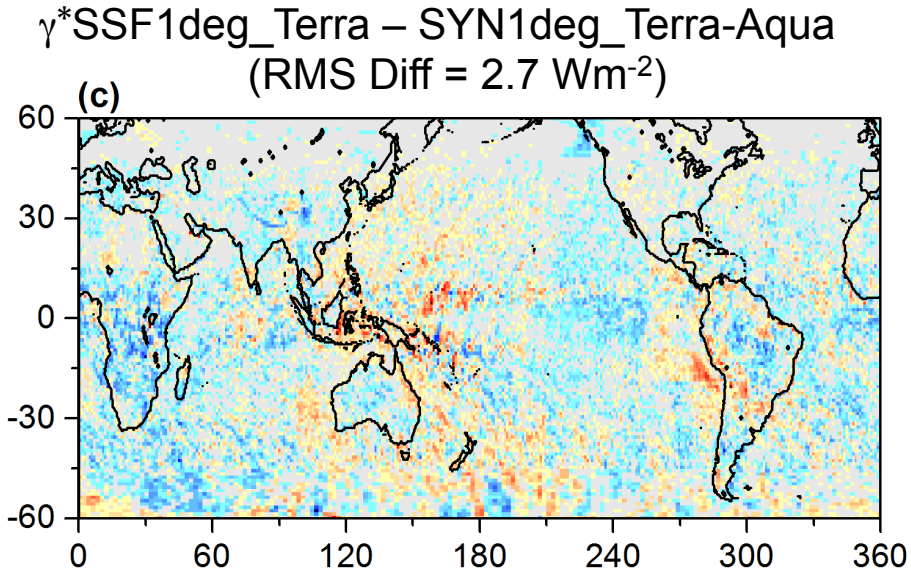


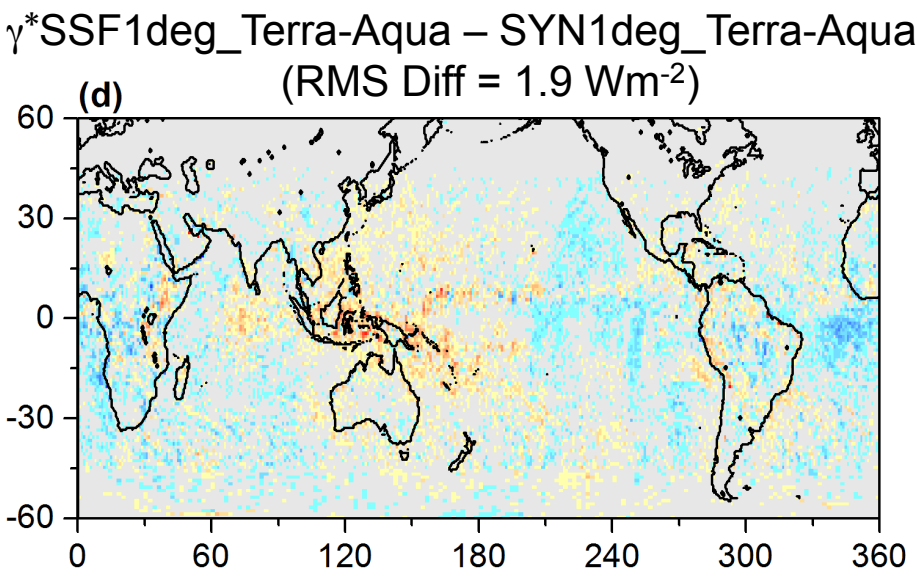


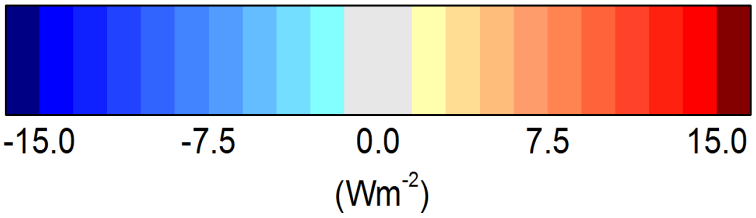


- Combining Terra and Aqua SSF1deg significantly reduces the regional bias compared to Terra-Only SSF1deg.

All-sky SW TOA Flux Difference: With Diurnal Correction (October 2008)



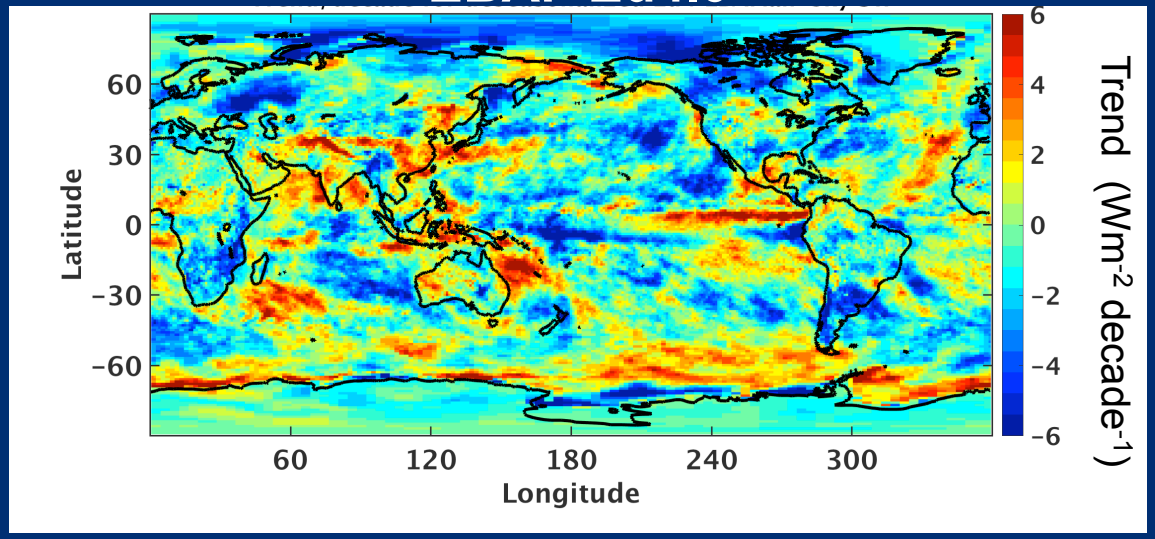




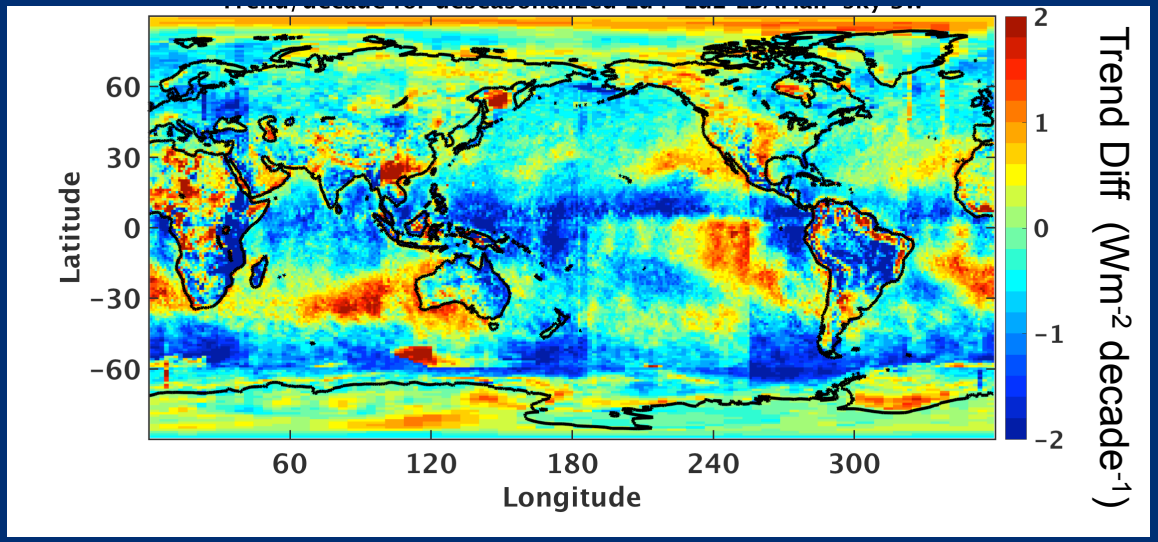
γ=Diurnal Correction Ratio

All-Sky SW TOA Flux Trend (03/2000-06/2015)

EBAF Ed4.0



EBAF Ed4.0 minus Ed2.8



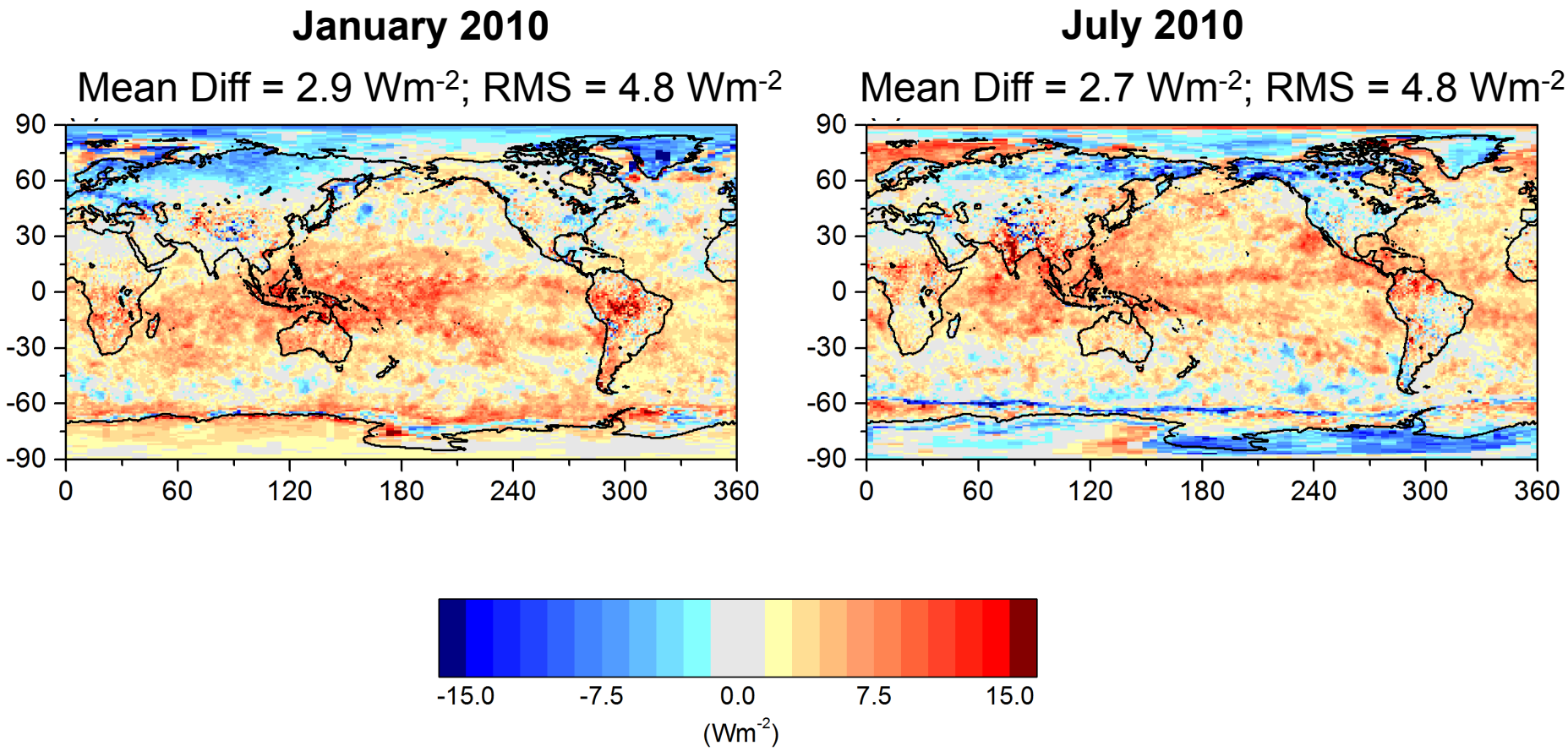
- Geostationary satellite boundaries appear in Ed2.8 trends, not Ed4.0.
- Improved Ed4.0 diurnal corrections avoid discontinuities due to geostationary satellite artifacts.

Global Mean TOA Flux (Wm^{-2}) (July 2005 – June 2015)

	All-Sky		Clear-Sky		CRE	
	Ed2.8	Ed4.0	Ed2.8	Ed4.0	Ed2.8	Ed4.0
SW	99.6	99.1	52.5	53.3	-47.1	-45.8
LW	239.6	240.1	265.4	268.1	25.8	27.9
NET	0.63	0.71	21.9	18.6	-21.3	-17.9

All-Sky TOA Flux Uncertainties (1σ):
SW: $\pm$ 1 Wm^{-2}
LW: $\pm$ 2 Wm^{-2}

EBAF Ed4.0 minus Ed2.8 **Clear-Sky LW** TOA Flux Difference

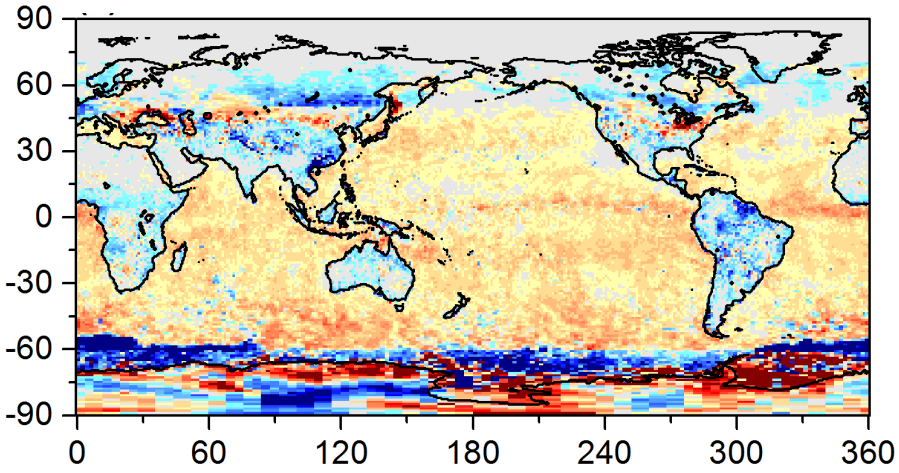


- EBAF Ed4.0 provides better screening for thin cirrus cloud contamination due to new threshold tests involving the MODIS 1.38 μm channel and other tests like T3.7-T11, T11-T12, ratio of 2.1 to 0.6, and VIS tests.

EBAF Ed4.0 minus Ed2.8 **Clear-Sky SW** TOA Flux Difference

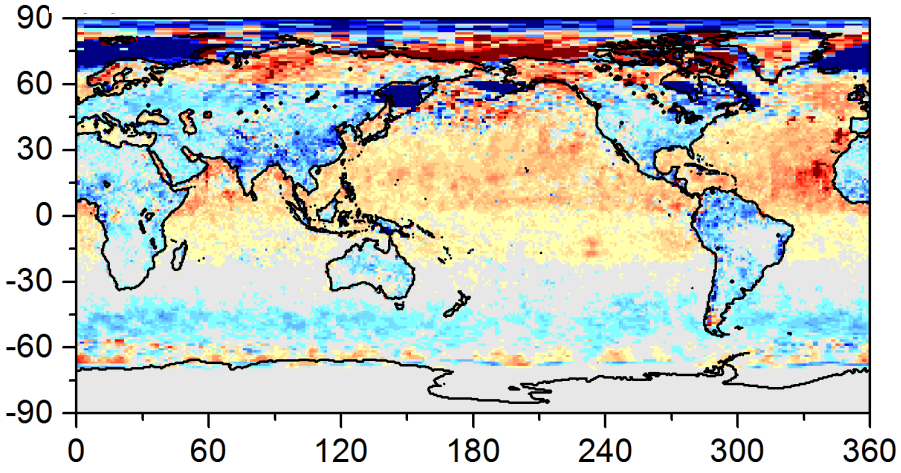
January 2010

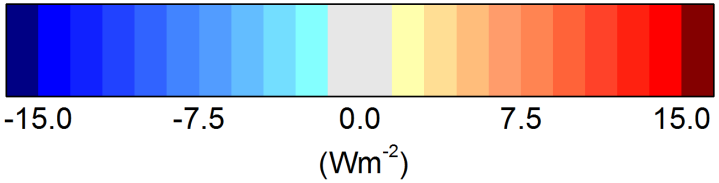
Mean Diff = 1.5 Wm^{-2}; RMS = 6.9 Wm^{-2}



July 2010

Mean Diff = 0.4 Wm^{-2}; RMS = 8.0 Wm^{-2}



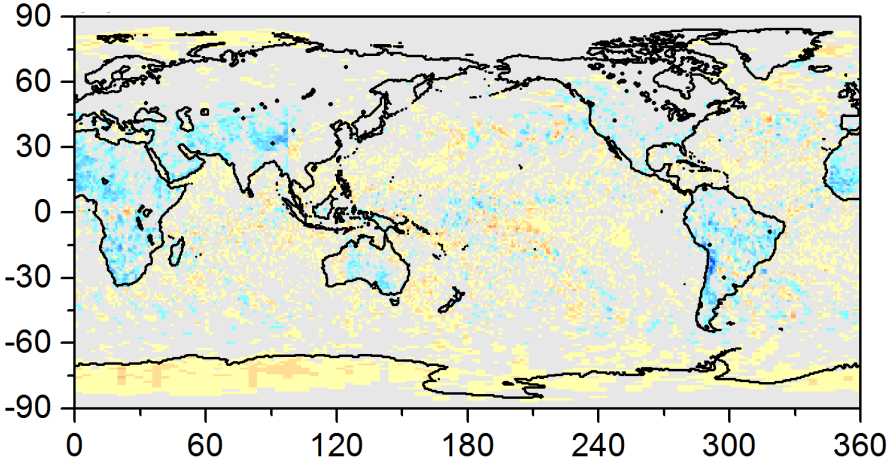


- EBAF Ed4.0 provides better identification of dust compared to Ed2.8 due to the addition of a 1.24/0.65 μm MODIS radiance ratio test in the cloud mask.
- Directional model bug fix increases clear-sky TOA flux, especially over ocean.

EBAF Ed4.0 minus Ed2.8 **All-Sky LW** TOA Flux Difference

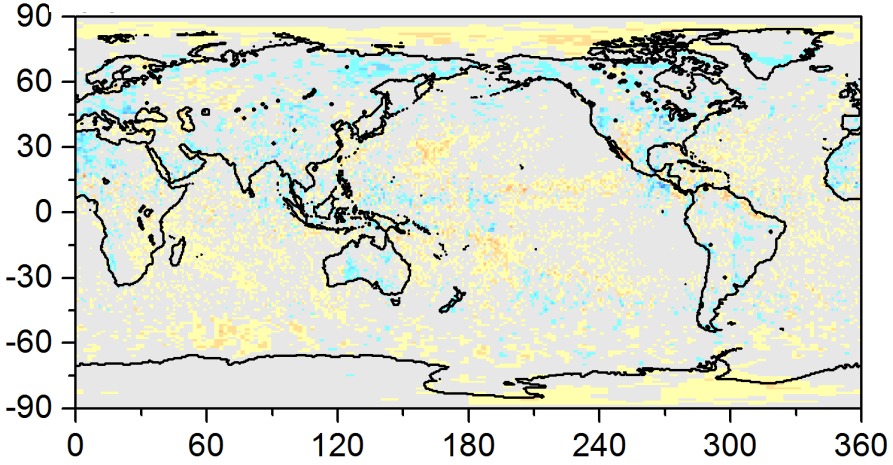
January 2010

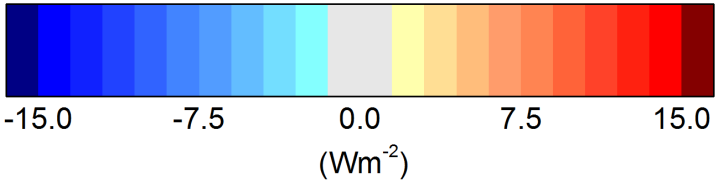
Mean Diff = 0.6 Wm^{-2}; RMS = 1.6 Wm^{-2}



July 2010

Mean Diff = 0.6 Wm^{-2}; RMS = 1.5 Wm^{-2}

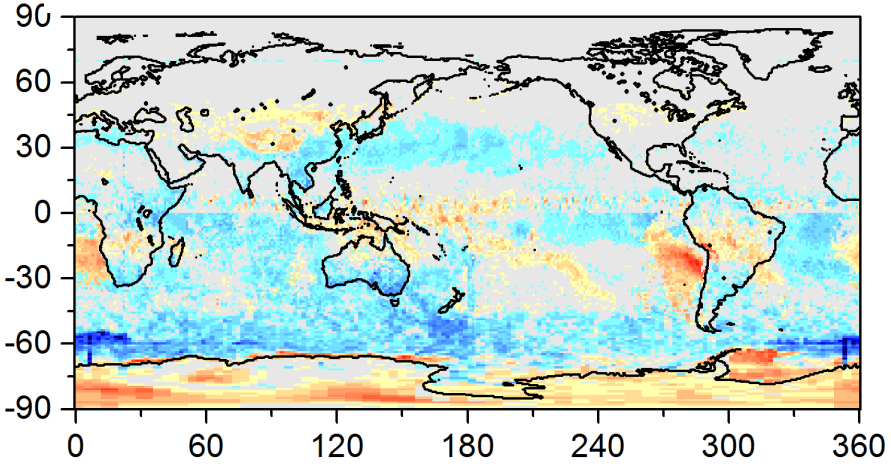




EBAF Ed4.0 minus Ed2.8 **All-Sky SW** TOA Flux Difference

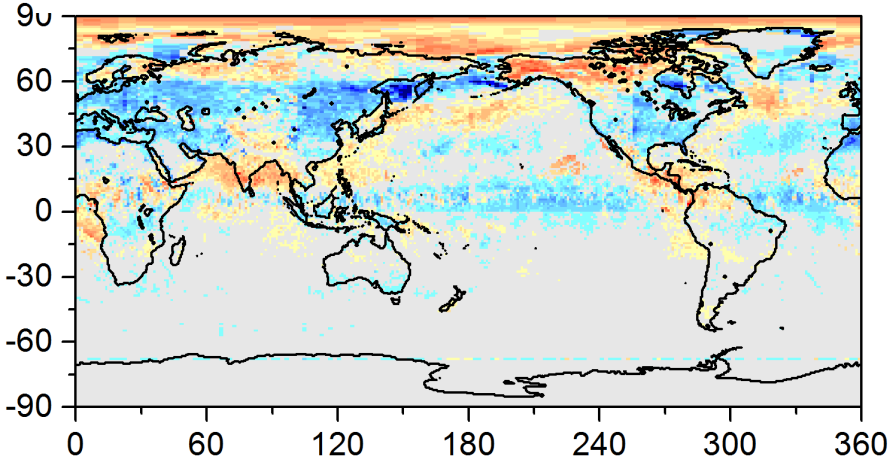
January 2010

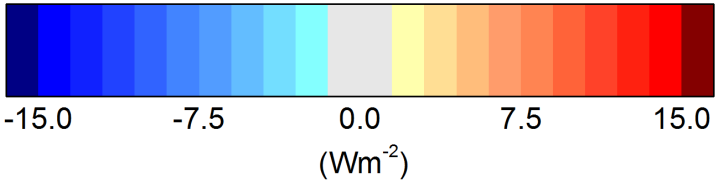
Mean Diff = -0.5 Wm^{-2}; RMS = 2.5 Wm^{-2}



July 2010

Mean Diff = -0.2 Wm^{-2}; RMS = 2.5 Wm^{-2}





1◦x 1◦ Regional Monthly Mean TOA Flux Uncertainty (1σ)

	All-Sky		Clear-Sky	
(Wm^{-2})	SW	LW	SW	LW
Terra-Only (03/2000-06/2002)	3	3	6	5
Terra-Aqua (07/2002-onwards)	2.5	2.5	5	4.5

All-Sky TOA Flux Uncertainty Contributions:

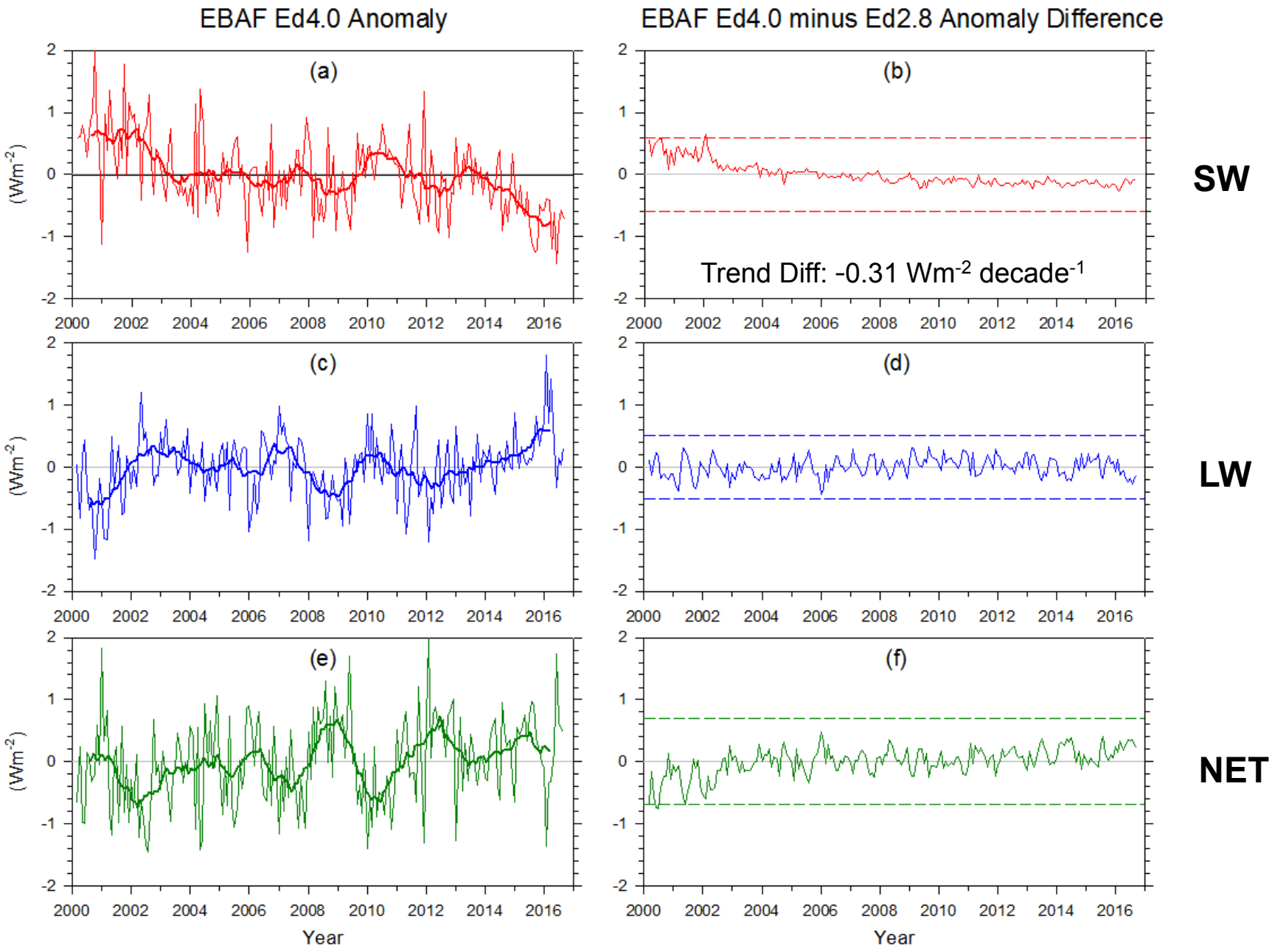
- Instrument calibration, radiance-to-flux conversion, diurnal correction.

Clear-Sky TOA Flux Uncertainty Contributions:

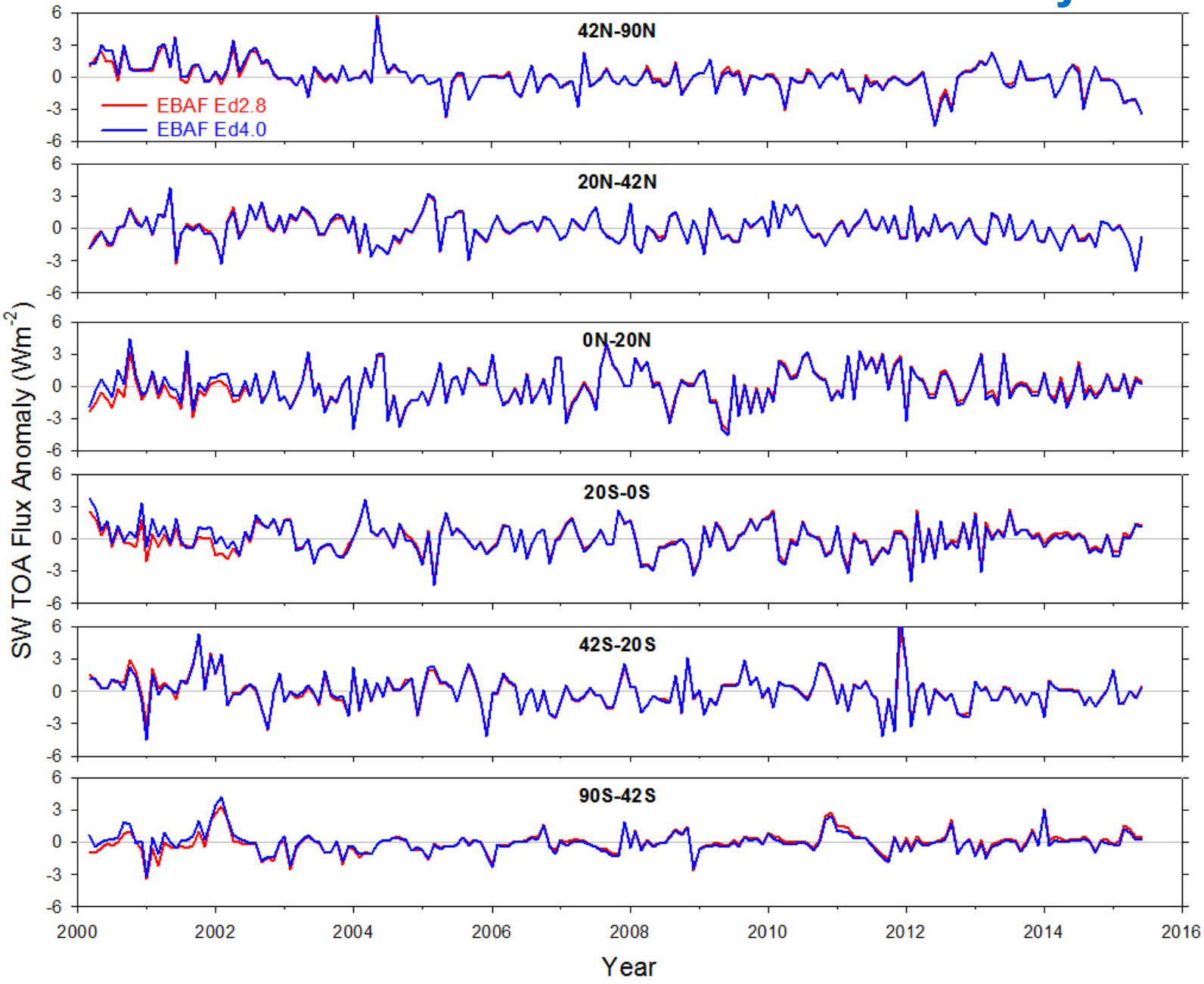
- Instrument calibration, radiance-to-flux conversion, diurnal correction.
- Narrow-to-broadband conversion, scene identification.
- Additional error to Terra-only period to ensure consistency with Aqua after 07/2002

Note: Uncertainties in regions with strong diurnal cycles can be larger than overall error due to greater diurnal correction error.

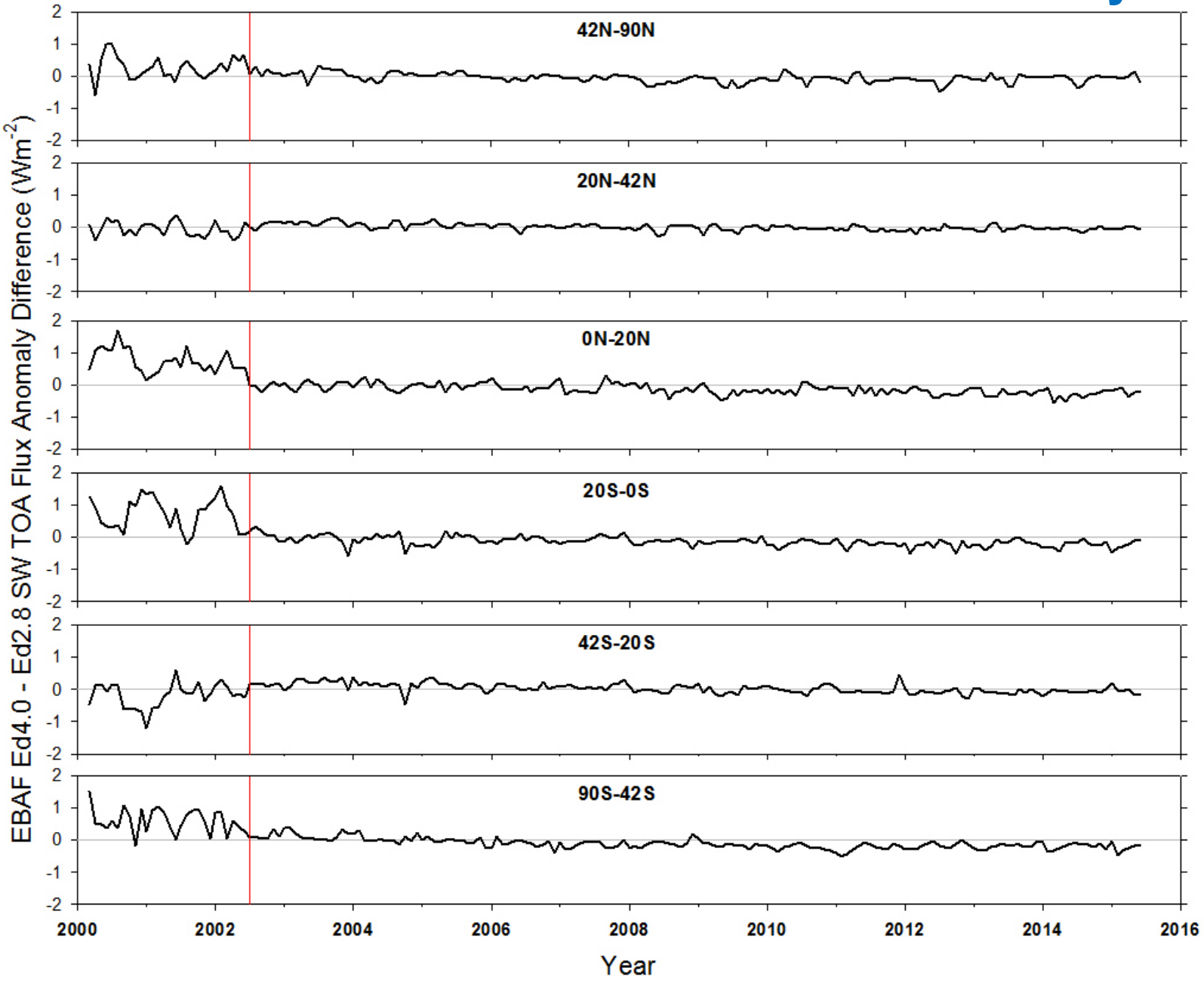
Anomaly in Global Mean All-Sky TOA Flux

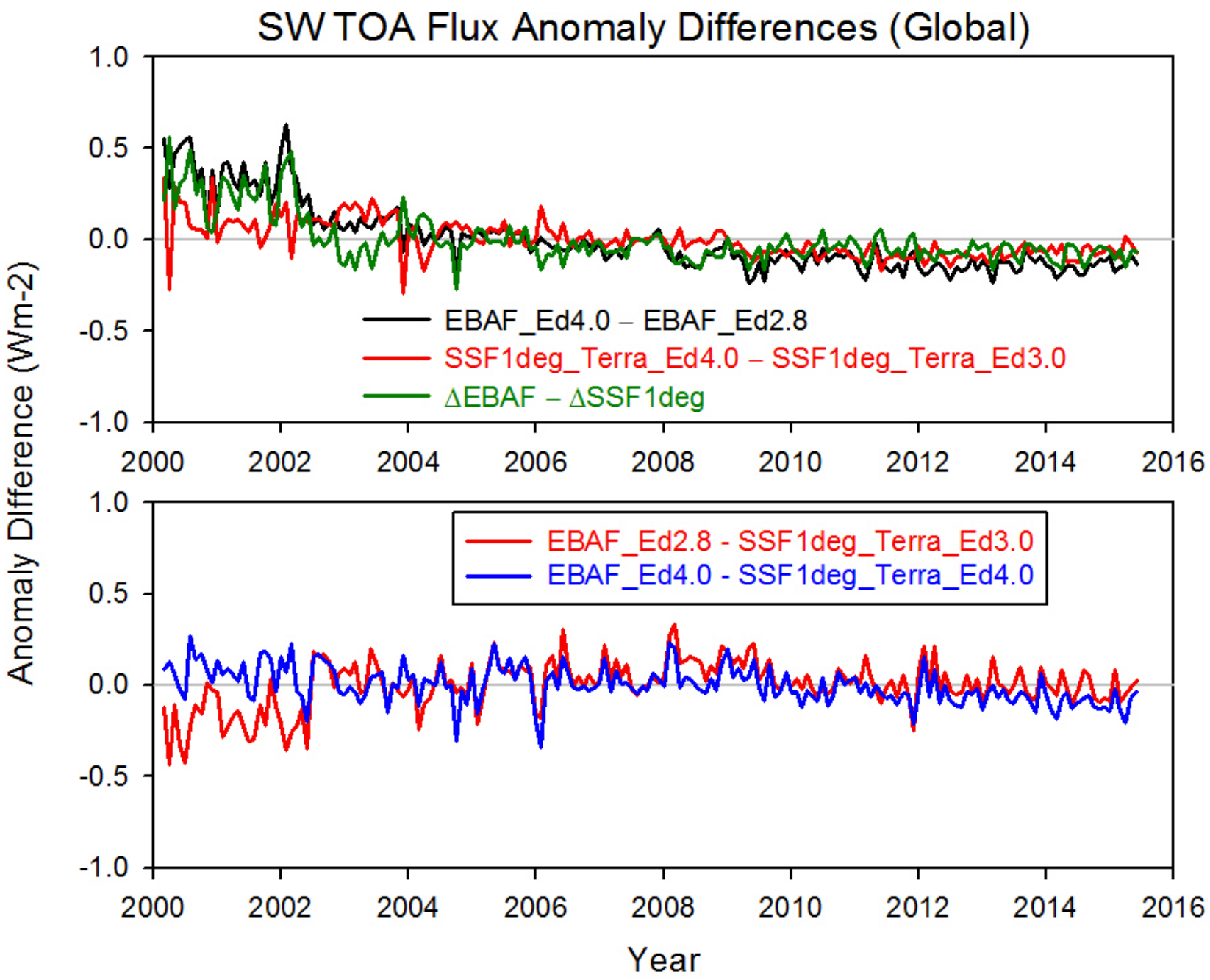


EBAF Ed2.8 & Ed4.0 SW TOA Flux Anomaly



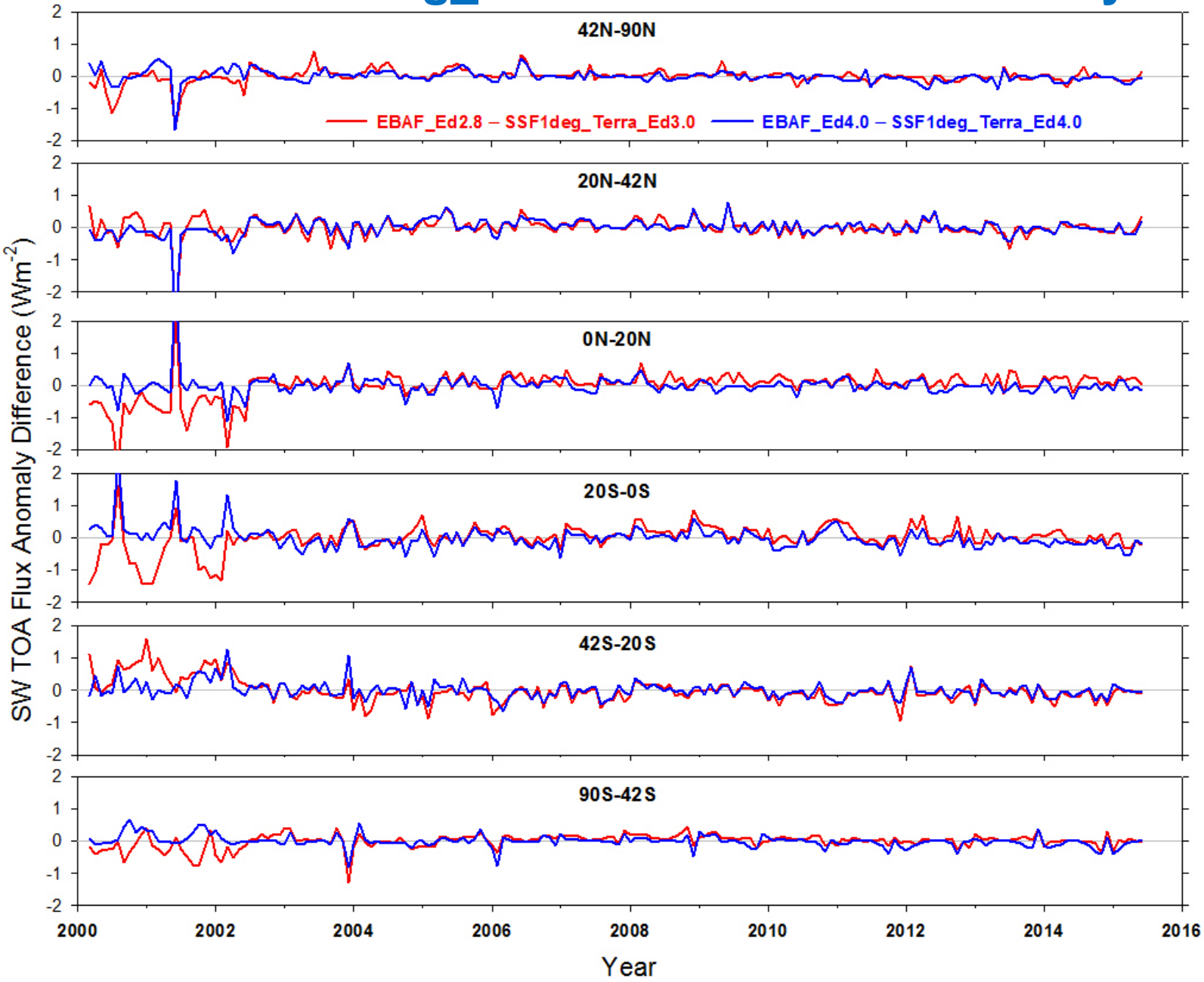
EBAF Ed4.0 minus Ed2.8 SW TOA Flux Anomaly



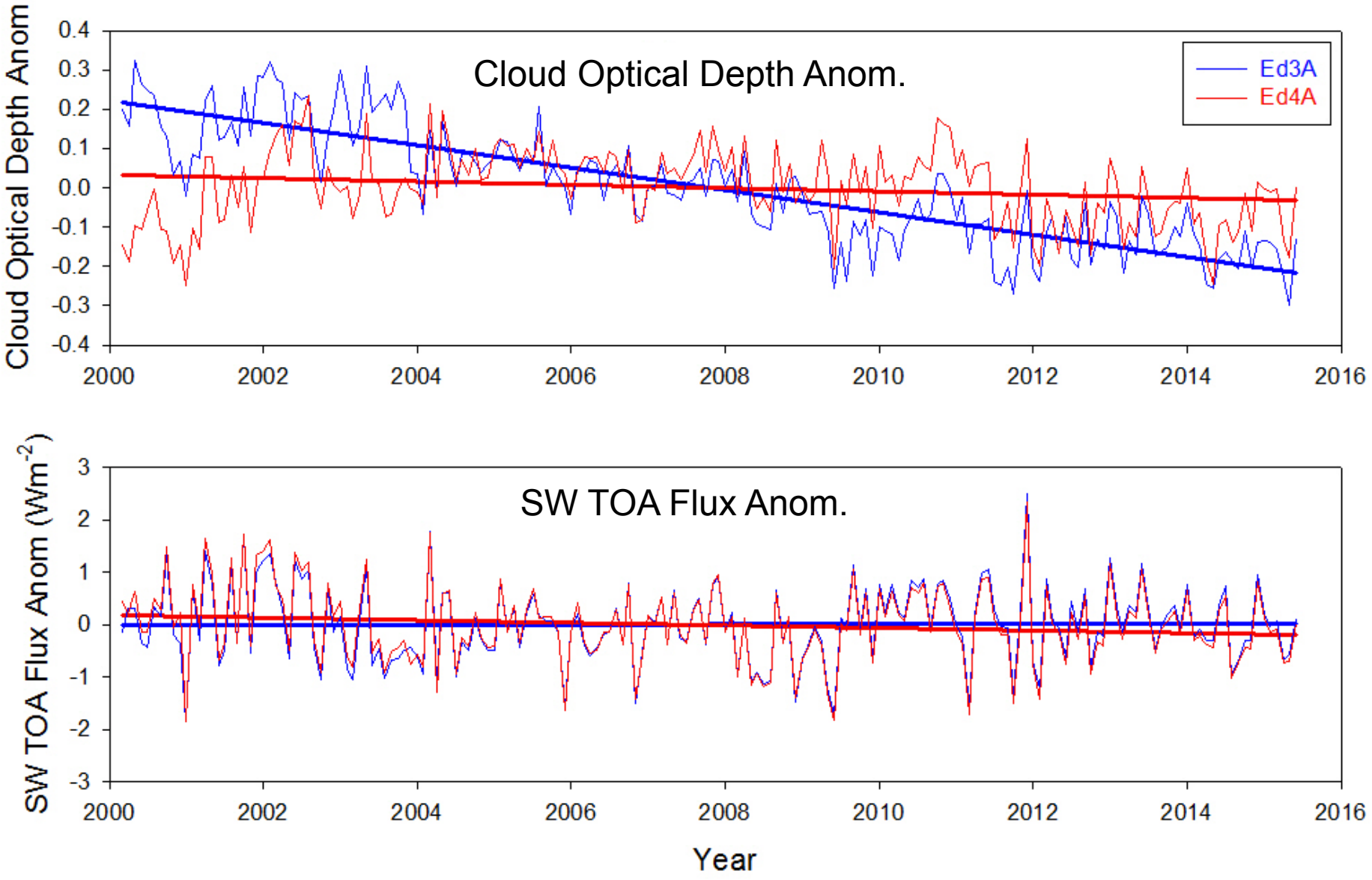

SW TOA Flux Anomaly Differences (Global)
Anomaly Difference (Wm-2)
1.0
0.5
0.0
-0.5
-1.0
2000
2002
2004
2006
2008
2010
2012
2014
2016
EBAF_Ed4.0 – EBAF_Ed2.8
SSF1deg_Terra_Ed4.0 – SSF1deg_Terra_Ed3.0
ΔEBAF – ΔSSF1deg
EBAF_Ed2.8 - SSF1deg_Terra_Ed3.0
EBAF_Ed4.0 - SSF1deg_Terra_Ed4.0
Year

Ed4.0 minus Ed2.8 SW TOA Flux Anomaly Difference

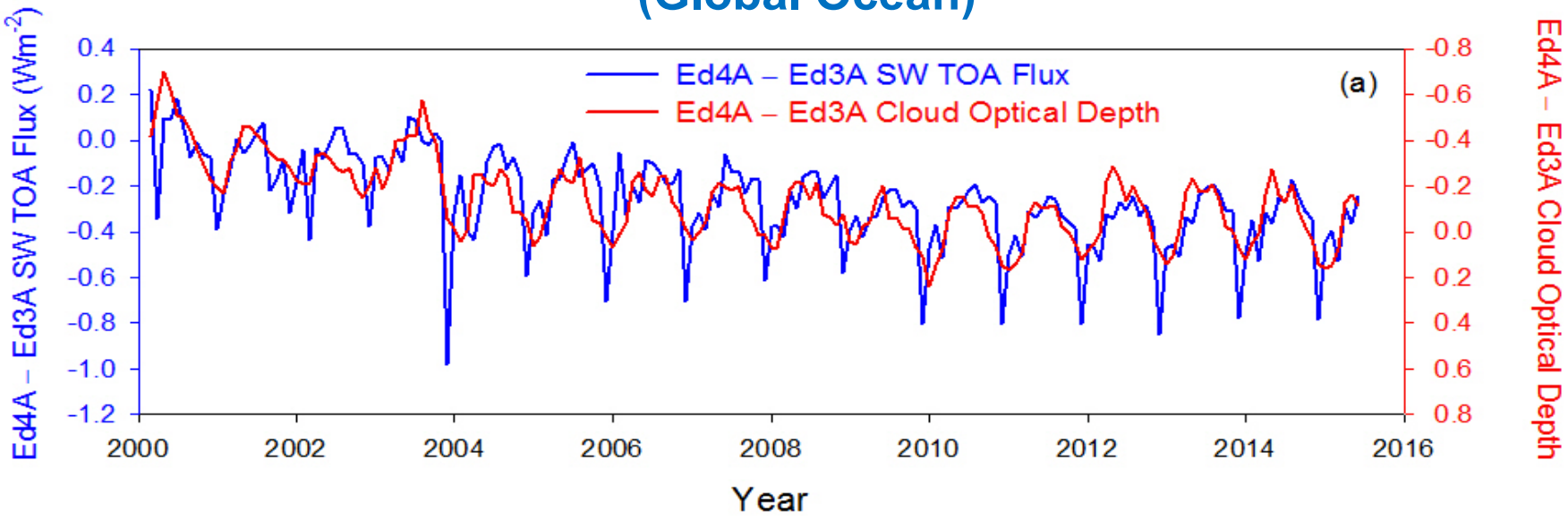
EBAF minus SSF1deg_Terra SW TOA Flux Anomaly Diff

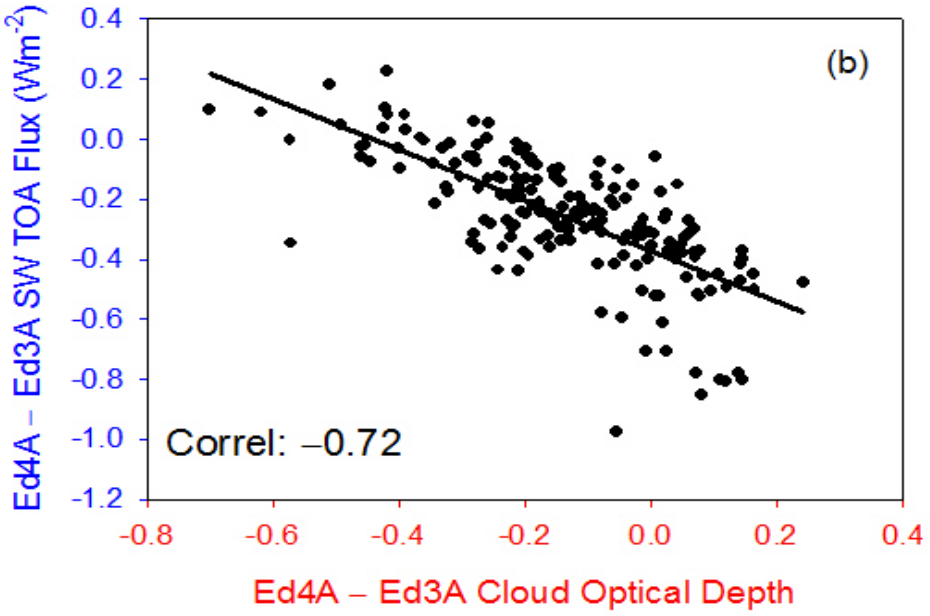


SSF1deg Ed3A and Ed4A Anomalies in Cloud Optical Depth and SW TOA Flux (Global Ocean; 03/2000-06/2015)

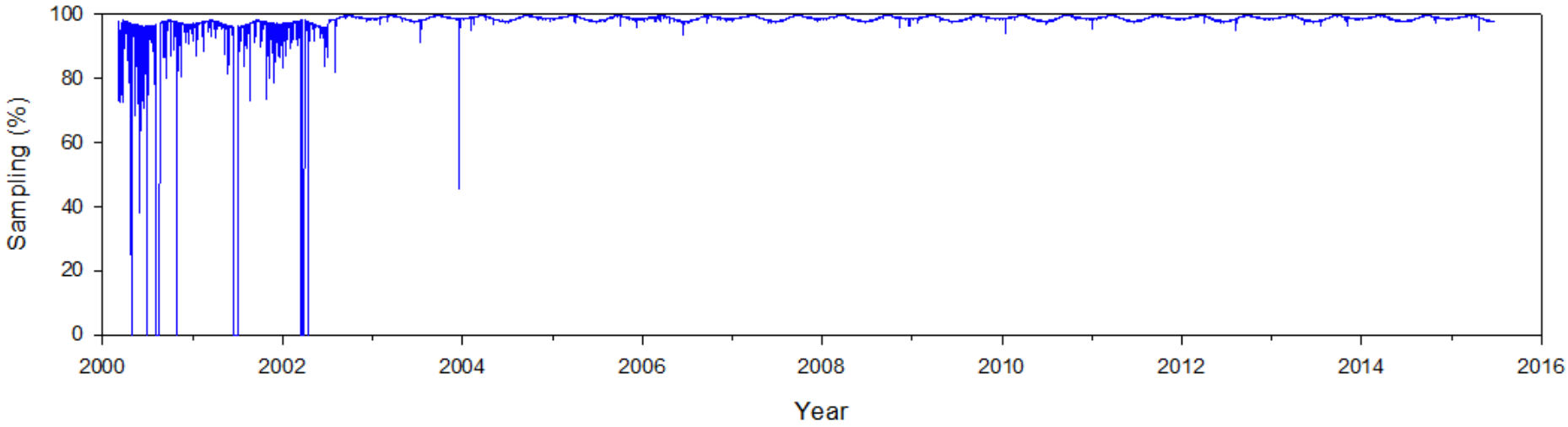


SSF1deg Ed4A minus Ed3A SW TOA Flux and Cloud Optical Depth (Global Ocean)





Global Area Weighted Daily Sampling in EBAF Ed4.0 (March 2000-June 2015)



Summary

- EBAF Ed4 incorporates the many improvements that are part of the Edition 4 suite of CERES data products (Level 1-3).

- EEI constraint will be based upon new 10-year Argo estimate.

- EBAF Ed4 clear-sky TOA fluxes differ markedly from Ed2.8:

  - Global annual mean SW TOA flux increases by 0.8 Wm^{-2}

  -Global annual mean LW TOA flux increases by 2.7 Wm^{-2}

  => Net CRE changes from -21 to -18 Wm^{-2}.

- Large reduction in LW clear-sky trend owing to consistent reanalysis (GEOS 5.4.1) throughout record.

- MODIS cloud properties are provided alongside TOA fluxes.